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Meeting the grand challenge for future carbon management engineers and scientists: stimulating workforce capacity through teacher professional development

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Abstract

In 2008 the National Academy of Engineering (NAE) announced a list of fourteen Grand Challenges for Engineering in the 21st Century that includes the challenge to "Develop carbon sequestration methods". The NAE highlighted the importance of creating an awareness of and involvement in the Grand Challenges for the pre-university community in order to (1) strengthen the technical workforce pipeline, (2) develop technical literacy and motivation needed for the global society to address these challenges, and (3) educate the general public on engineering and its role in addressing these challenges and improving the quality of life. In 2009, we initiated a program funded by the United States Department of Energy to increase workforce capacity for the geological carbon storage (GCS) industry. As part of this initiative, we have forged alliances to bring high-quality curriculum related to GCS to pre-university classrooms, and to provide teachers an opportunity to introduce curriculum on one of the Grand Challenges for Engineering into their classroom.

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1. Introduction

In 2008 the National Academy of Engineering (NAE), a government-created non-profit institution in the United States, announced a list of fourteen Grand Challenges for Engineering in the 21st Century [1]. The list of challenges was created by an international committee of technological leaders, with input from

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both the public and external experts. “Develop carbon sequestration methods” is one of these fourteen Grand Challenges (Table 1). As one of the Grand Challenges, carbon sequestration is highlighted as a good, short-term engineering solution to a global societal problem. The NAE highlighted the importance of creating an awareness of and involvement in the Grand Challenges for the pre-university community to (1) strengthen the science, technology, engineering and math workforce pipeline, (2) develop the technical literacy and motivation needed for the global society to address these challenges, and (3) educate the general public on engineering and its role in addressing these challenges and improving the quality of life.

Table 1. The Grand Challenges for Engineering in the 21st Century as put forward by the National Academy of Engineering [1].

National Academy of Engineering: **Grand Challenges for Engineering**	
1. Make solar energy economical	8. Engineer better medicines
2. Provide energy from fusion	9. Reverse-engineer the brain
3. Develop carbon sequestration methods	10.Prevent nuclear terror
4. Manage the nitrogen cycle	11.Secure cyberspace
5. Provide access to clean water	12. Enhance virtual reality
6. Restore and improve urban infrastructure	13. Advance personalized learning
7. Advance health informatics	14. Engineer the tools of scientific discovery

In 2009, a group of scientists and engineers involved in carbon capture and storage at The University of Texas funded by the U.S. Department of Energy, established the STORE (Sequestration Training, Outreach, Research and Education) alliance to carry out the mission of developing a future workforce to support the commercial deployment of carbon sequestration technologies. As part of this workforce initiative, we forged alliances with teacher networks, teacher associations, teacher professional development programs, outreach programs, industry and professional societies to bring high-quality curriculum related to geological carbon storage (GCS) to the middle- and high-school classroom (students typically ranging from 10 to 18 years of age). These inquiry-based activities, although focused on the topic of carbon storage, satisfy many state (Texas) and national (U.S.) education requirements for teaching science, technology, engineering and math. By bringing GCS activities into the pre-university educational environment, we provide teachers an opportunity to expose their students to one of the Grand Challenges for Engineering in the 21st Century.

2. Creating Alliances

By establishing broad alliances, STORE has been able to leverage resources for content, expertise, materials, opportunities and teachers to create a successful model for education and outreach across the large culturally and geographically diverse area of Texas (~700,000 km^2) that has almost 26 million residents, the second largest state in the U.S. Through the authors’ involvement with various teacher development programs in Texas over the last decade, we are aware that working through an alliance is an excellent way to multiply the effectiveness of our efforts.

2.1. STORE and the TeXas Earth and Space Science (TXESS) Revolution

Since its inception, STORE has partnered with an Earth science teacher professional development program at The University of Texas at Austin. The Texas Earth and Space Science (TXESS) Revolution was initiated with sponsorship from the National Science Foundation and has provided teacher professional development to multiple cohorts of teachers since 2007 [2]. This partnership has allowed us to reach a diverse population and ensure that our curriculum covers important national and state science literacy standards.

Through our activities, STORE used elements of the TXESS Revolution model by instituting four of its six key principles: (1) model best practices in workshop presentations; (2) use authentic earth science data and cybertechnology to teach up-to-date content; (3) provide ongoing training to cohorts of learners; and (4) use ongoing evaluation to guide future workshops [2]. These principles have contributed greatly to the success of STORE's teacher professional development. We hope to be able to implement two other TXESS Revolution principles as the program grows: (1) involve geoscience consortia and programs that can provide proven content for classrooms; and (2) provide opportunities for teachers to participate in research and curriculum development projects [2].

STORE has partnered with the TXESS Revolution to design and deliver curricula covering broad energy themes, most recently, "Energy, Climate and Water in the 21st Century". This two-week, summer workshop was held in 2011 at the Department of Petroleum and Geosystems Engineering and the Institute for Geophysics, both at The University of Texas at Austin. The workshop was comprised of various activities and labs related to GCS and energy (Fig. 1): drilling and simulation lab, petrophysics lab, petroleum geology activity, reservoir engineering lab, volumetrics activity, well stimulation problem set, climate change activities, CO_2 injection activities (*Injection of CO_2 in Geological Formations*) [3], properties of CO_2 lab and carbon storage technology, adaptation of the *Stabilization Wedges Game* [4], water resources activity, water quality monitoring and testing lab. Activities were developed or adapted specifically for this workshop through a collaborative effort between TXESS Revolution and STORE.

Fig. 1. Teachers from a summer institute at The University of Texas at Austin working on *CO_2 Injection for Geological Storage* activities. (a) A petroleum engineering professor from the university discusses CO_2 storage with a high school Earth Sciences teacher. (b) Teachers examine tubes packed with beads of different sizes to better understand capillary seals for buoyant non-aqueous phases (red).

One of the important benefits of our partnership with the TXESS Revolution is that project's focus on evaluation. During workshops, professional evaluators measured the gains made by project participants using both qualitative and quantitative measures. TXESS Revolution administered pre- and post-tests to document teacher gains in content knowledge (typically >90% of teachers made significant gains based on metrics employed by the Math Science Partnership of the Department of Education) and to identify when teachers arrived with misconceptions related to STORE workshop content and themes.

In addition, results of satisfaction surveys allowed us to make changes in delivery and content in response to teacher feedback. Quantitative research techniques were used to evaluate each major component of a workshop. Participants were asked to use a 5-point Likert scale (1 = not at all; 5 = very much) to rate each activity for the workshop based on the following three dimensions: (a) The activity was interesting, (b) the activity was applicable for implementation of guided inquiry, and (c) the activity was applicable for use of in-class technology. These three items were averaged for each activity, and across all activities involved, to form a composite quality index [2]. It is a testament to the willingness of scientists, engineers and faculty at The University of Texas at Austin to create hands-on, inquiry-based activities, which modeled best-practices in workshop presentation, that the 2011 "Energy, Climate and Water in the 21st Century" two-week, summer workshop received a 4.5/5.0 composite quality index from the teachers who participated in the program.

From the beginning of the TXESS Revolution program, qualitative research techniques, in the form of unobtrusive interviews and focus groups, were used to gather feedback from participants. These data shaped the format and content of subsequent workshops, and our STORE program benefitted greatly from this feedback when we partnered with TXESS Revolution. Teacher suggestions were taken seriously by STORE instructors who used them to improve the professional development, content, delivery and organization; teachers appreciated their thoughts and concerns being taken seriously [2].

2.2. STORE and the Texas Regional Collaboratives for Excellence in Science and Mathematics

STORE has also worked with the Texas Regional Collaboratives (TRC) for Excellence in Science and Mathematics Instruction (Fig. 2a), a program of networked-partners who focus on providing sustained, high-intensity professional development for teachers across the entire state of Texas [5]. This alliance helps us in two primary ways: (1) recruiting teachers and (2) multiplying the benefits of our programs.

Because we are partnering with the TRC, their professional development coordinator helps us recruit teachers by advertising through the TRC's communications network of teachers across the state. Their 2010-2011 science collaborative membership was 5,450 teachers throughout the state [6].

The program subscribes to the 'train the trainer' model, that is, the TRC requires all of its teachers who attend TRC sponsored workshops to go back to their local, educational districts and train at least an additional 25 teachers. Because many of the teachers in our workshops are members of a Regional Collaborative, this TRC requirement multiplies our impact. For example, when a teacher who attended the 2011 "Energy, Climate and Water in the 21st Century" workshop (see section 2.1 above), put on her own local workshop featuring GCS and energy themes ("Energy Resources: Engineering and Earth Science

Concepts for the Classroom") for the Region 1 Collaborative teachers in south Texas, it expanded the impact of our curricula to reach an additional 32 teachers (Fig. 2b). With estimates of each teacher reaching, on average, approximately 64 students each year [6], the reach of that one workshop broadens to potentially around 2,000 students per year. Thus, our "Energy, Climate and Water in the 21st Century" workshop with 24 teachers, had the potential to reach approximately 40,000 students.

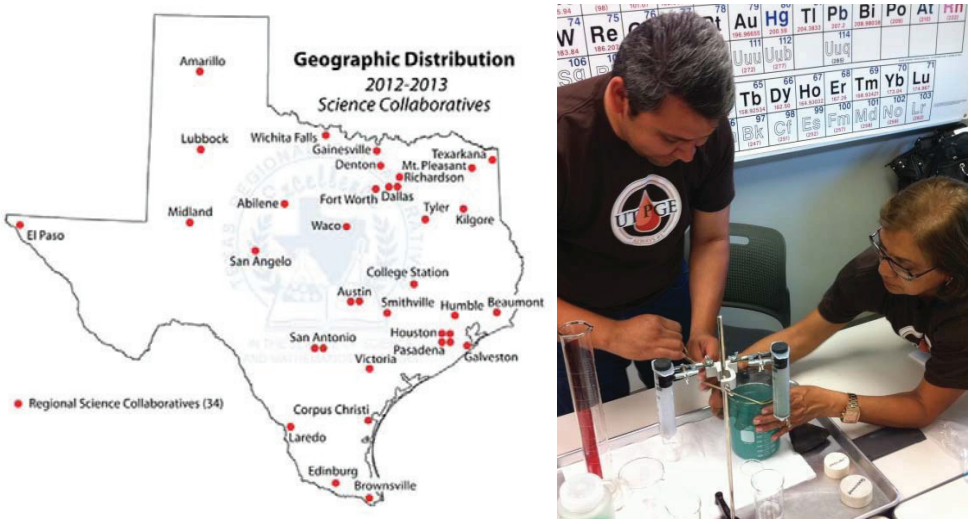

Fig. 2. (a) Map showing the location of Texas Regional Collaborative (TRC) science centers across the state. Each Regional Collaborative is led by a Project Director and Instructional Team Members who provide direct professional development to teachers of science [5]. (b) Teachers doing porosity and permeability experiments at a STORE/TXESS Revolution/TRC partner workshop in the Region 1 Collaborative in Edinburg in south Texas. Teachers in this collaborative are from fourteen different school districts across South Texas.

In addition, the TRC has an annual meeting in Austin, Texas for teachers. Because of our alliance, they asked us to partner on an event for the most recent 18th Annual Meeting. STORE worked with the TRC, the TXESS Revolution and the Department of Petroleum and Geosystems Engineering to host the Annual TRC Meeting's Shell Field Trip at the department on The University of Texas at Austin main campus. Expert engineers and geologists were featured at a symposium on "Energy, Engineering and the Environment." Drilling challenges, injection of fluids in the subsurface and carbon storage technology were all highlighted during the half-day symposium.

2.3. STORE and GeoFORCE Texas

We have also partnered with GeoFORCE Texas, an experiential outreach program that prepares Texas high school students (ages 14-18 years) to become part of the geosciences workforce. The program in Texas is designed "to encourage students from minority-serving high schools in rural South Texas and

inner-city Houston to take on the challenges of a rigorous math and science curriculum, to pursue higher education in these fields, and to enter the high-tech workforce" [7].

GeoFORCE provides professional development for middle school teachers in their geographic recruiting areas. These workshops and field trips provide teachers with classroom resources, and they give educators a taste of what the GeoFORCE Texas program has to offer. These teachers keep their middle school students (ages 11-14 years) excited about Earth sciences in the years leading up to the time when the students can apply to the GeoFORCE program (i.e., high school).

In the spring of 2011, STORE provided a two-day workshop for 45 middle school teachers on "Energy and You: What to do with CO_2." The workshop included numerous activities and field trips related to GCS and energy, including activities specifically created by or adapted by STORE (Fig. 3). The activities had previously been tested and evaluated in partnership with the TXESS Revolution program. The workshop received high marks from teachers for content, presentation and organization.

Fig. 3. Teachers from the GeoFORCE Texas program at The University of Texas at Austin participated in a workshop organized by STORE in 2011. (a) A petroleum engineering professor discusses porosity and permeability in carbonate rocks on a half-day field trip as part of the workshop; (b) A researcher from the Bureau of Economic Geology at the university assists teachers with an adaptation of the *Stabilization Wedges Game* [4].

2.4. STORE and Industry Partners

Industry partners have assisted our teacher professional development programs through sponsorships. But the most unique contribution from these industry partners is to allow our teachers to visit their day-to-day operations and envision the future role of the budding scientists and engineers currently in the teachers' classrooms.

STORE, TXESS Revolution and GeoFORCE Texas have been fortunate to include field trips to innovative visualization facilities, wellsites, coal-fired power plants and coal mines run by our partners from the fossil fuel industry (Fig. 4). These types of trips enhance classroom activities, such as *Injection of CO_2 for Geological Storage,* and infuse teachers with enthusiasm for the subject matter.

Fig. 4. Teachers from a summer institute at The University of Texas at Austin visit a local coal-fired power plant, the adjacent coal mine and the reclaimed area previously mined during a STORE-sponsored field trip.

2.5. STORE and Professional Society Partners

In addition to industry partners, professional societies have been helpful in supporting our educational initiatives for teachers. An example is the Society of Petroleum Engineers (SPE) *Oil and Natural Gas* book as part of their energy4me program. Teachers receive one complimentary classroom book from the website (http://www.energy4me.org), and also may request a classroom speaker [8]. The SPE has often allowed us to give out these complimentary classroom copies as part of our workshop programs. The society also has free corresponding lesson plans with experiments that can be downloaded from their website. The books and lesson plans are available in Arabic, Chinese, English, French, Russian, and Spanish, and could be easily used in similar teacher professional development workshops in other countries.

3. Summary

Teacher professional development provided by STORE and its partnerships is providing educators with an introduction to one of the Grand Challenges for Engineering in the 21st Century. Our workshops highlight the global and local importance of energy, and the scientific and technological challenges of implementing carbon sequestration methods. Through our alliances, we have been able to leverage resources for content, expertise and teachers to create a successful model for education and outreach. We have developed and taught inquiry-based activities focused on carbon storage. These curricula satisfy many state and national education requirements for teaching science, technology, engineering and math.

Evaluation with partnering programs demonstrates that educators who attend our workshops leave with greater subject knowledge content and tools they can implement in their classroom. These teachers leave our workshops positive about their professional development experience and passionate about the opportunities for engineering to address energy and climate change issues. And, they multiply our effectiveness by taking their increased content knowledge and transferring it to their own students and to other teachers, helping us meet the grand challenge of providing future carbon management engineers and scientists.

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